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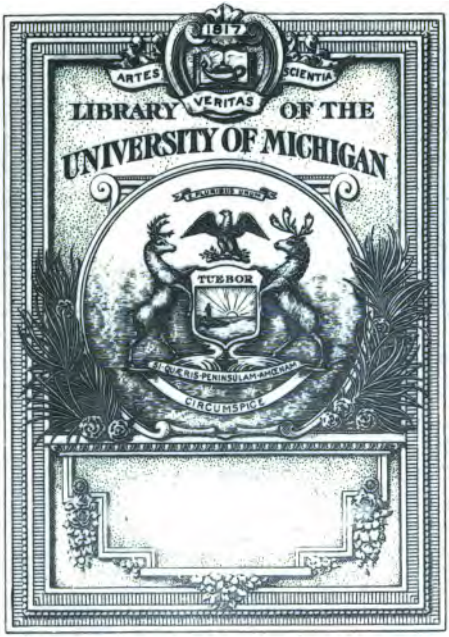
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DERIVATION OF PRACTICAL

ELECTRICAL UNITS.

WITH TWELVE ILLUSTRATIONS.

BY LIEUT. F. B. BADT
— AND —
PROF. H. S. CARHART.

SECOND EDITION.

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PREFACE.

The matter contained in the following pages is, in the main, a reprint of articles published in the WESTERN ELECTRICIAN. This little book is issued in response to a general demand that the articles be printed in such form that they might be available for ready reference. The biographies of the eminent physicists, whose names have been selected to designate the practical electrical units, comprehend much that is most interesting and most important in the history of electrical science. The preparation of the brief sketches and the obtainment of the accompanying portraits involved no little labor on part of LIEUT. F. B. BADT, who compiled the matter in the first instance. The work was undertaken, however, as the desirability of rendering the information easily accessible seemed so apparent. PROF. H. S. CARHART'S valuable article relating to the modifications to which several of the electrical units are subject is included in the little volume.

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DERIVATION
OF
PRACTICAL ELECTRICAL UNITS.

BY F. B. BADT.

CHAPTER I.

INTRODUCTION.

The statement is frequently made that the calculations of electricians are mere guesswork, because we do not understand the nature of electricity. Such an assertion is, of course, absurd. Mathematics is an exact science, whether applied to astronomy, hydraulics or electrical engineering. While they do not know what gravitation is, astronomers are able to calculate eclipses of the sun and moon, and the movements of celestial bodies, with absolute accuracy. Thus it is in dealing with electricity; while we know little of its nature, we are still enabled by means of mathematics and by a knowledge of the simple laws discovered by Ampere, Ohm, Joule and others, to make calculations with entire accuracy.

Gauss first proposed the substitution of absolute units for measuring electrical quantities in place of the arbitrary units used up to his time. He showed that all quantities could be referred to the fundamental units of length, time and mass. The unit of length now adopted is the centimeter; the unit of time is the second, and the unit of mass is the gramme. These units, which form the means of measurement called the Centimeter-Gramme-Second system, or the C. G. S. system, are known as the absolute or C. G. S. units.

Practical units, however, were adopted for the reason that the absolute units for the several electrical quantities were found to be either too great or too small for practical measurements. Multiples of the absolute units, therefore, were adopted as practical units, and the names of the most prominent scientists who had worked to build up a practical system of measurement, were selected as terms to designate them.

During the last few years the writer has received numerous letters asking for information relative to the derivation of these units. He had hoped that an adequate explanation of the origin of the terms would be found in Prof. Houston's "Dictionary of Electrical Words, Terms and Phrases," but he was disappointed. One looks in vain for derivations of the units and for biographies

of the scientists whose names are employed to designate them. That this information might be readily accessible, the writer undertook the preparation of this article.[1]

In the following pages are presented with one exception the portraits of all the eminent scientists by whose names the practical units are or were designated. The portrait of Coulomb is missing, and it is extremely doubtful if there is one extant. In the accompanying table is presented a summary of the information relating to the practical units. In the following chapters are presented short biographies of the eminent men whose work marked signal advances in scientific attainment, and whose names are or were the familiar designations of the practical units.

---

[1] The portraits presented in the following pages were obtained from friends in the United States and abroad. A large number of books and periodicals was consulted, both for portraits and biographies. The writer is especially indebted to Encyclopædia Britannica; E. Jacquez' Dictionaire d' Electricite et de Magnetisme; Otto Spamer's Conversationes Lexicon; Brockhaus' Conversationes Lexicon; *Popular Science Monthly;* Les Merveilles de la Science par Louis Figuier "Invention;" The London *Electrician* Trades' Directory; Hartleben's Electro-Technische Bibliothek, and many others.

CHAPTER II.

WILHELM EDUARD WEBER.

Wilhelm Eduard Weber was born at Wittenberg, October 24, 1804. In 1831 he was professor of physics at the University of Goettingen, and in 1843 was professor at the University of Leipzig. In 1849 he is found again at the University of Goettingen. He published with Gauss from 1836–'41 the results of observations of the Magnetic association. (See Gauss). In 1840 he published the "Atlas of the Earth's Magnetism." From 1846 to 1878 he compiled "Electro-Dynamische Massbestimmungen," (Electro-Dynamic Measurements). In this latter work Weber introduces the system of absolute units.

In the earlier stages of the science several units were introduced for the measurement of quantities dealt with in electricity. In illustration may be mentioned the wire of Jacobi (25 feet of copper wire weighing 345 grains), the mercury column of Siemens (a meter long with a section of a square millimeter), which at given temperatures furnished units of resistance, and the Daniell cell, which furnished the unit of electromotive force. Jacobi's current unit was based on the electrolytic decomposition of water. One cubic centimeter of oxy-hydrogen gas is

WILHELM EDUARD WEBER.

formed each minute. All these units were perfectly arbitrary, and there was no connection of any kind between them. The introduction of a rational system of unitation, based on the fundamental units of time, mass and length, was one of the greatest achievements of modern times. The impulse came from the famous memoir of Gauss, "Intensitas vis Magneticæ Terrestris ad Mensuram Absolutam Revocata" in 1832. (See Gauss.) In conjunction with Weber, he introduced his principles into the measurement of the earth's magnetic force.

To Weber belongs the credit of doing a similar service for electricity. He not only devised three different systems of such units —the electro-dynamic, the electro-static, and the electro-magnetic, but he carried out a series of measurements which practically introduced the last two systems.

The practical units which are in use to-day are simply certain multiples of the absolute or Centimeter-Gramme-Second (C. G. S.) units. The absolute units are either too great or too small for practical use and for convenience the "practical units" were adopted, to which the names of the most famous electricians are given.

Weber was the most illustrious among the successors of Ampere. (See Ampere.) He greatly improved the construction of the galvanometer, and invented the electro-dynamometer. To these instruments he applied the mirror scale and telescope method of reading which had been suggested by Poggendorff and used by him and Gauss in magnetic measurements about 1833. In 1846 he tested by means of his improved apparatus the fundamental laws of Ampere. The result of his researches was to establish the truth of Ampere's principles as far as experiments with closed circuits could do so, with a degree of accuracy far beyond anything attainable with the simple apparatus of the original discoverer.

Applying his improved instruments he also obtained accurate verifications of the laws of induction, which by this time had been developed mathematically by Neumann and himself. The experiments of Weber must be considered as the experimental evidence establishing the theory of Ampere, and as such they form one of the corner stones of electrical science. Clausius and Siemens proposed the term Weber for the practical unit of the strength of the magnetic pole. This unit is equal to 10^8 C. G. S. units. The term has not yet been generally adopted as a practical unit. The term Weber was formerly employed to designate the unit strength of current. This term is now replaced by the ampere.

[illegible] Brunswick, [illegible] Goettingen, Feb. 23, [illegible] humble parentage [illegible] thanks to the [illegible] appointed [illegible] Goettingen Observatory in [illegible] his death. [illegible] Magnetic [illegible] Review. [illegible] in con[illegible] Weber new [illegible] the earth's mag[illegible] the [illegible] ar [illegible] Weber's assistance he [illegible] Goettingen a magnetic [illegible] From this [illegible] signals to a [illegible] demonstrating for [illegible] of an electro[illegible] He organized the Mag[illegible] continuous obser[illegible] fixed days extended from

CARL FRIEDRICH GAUSS.

CHAPTER III.

CARL FRIEDRICH GAUSS.

Carl Friedrich Gauss was born at Brunswick, April 30, 1777, and died at Goettingen, Feb. 23, 1855. Gauss was born of humble parentage. He received an education, thanks to the notice which his talents procured for him from the reigning duke. He was appointed director of the Goettingen Observatory in 1807, an office which he retained to his death. The story goes that he always slept under the roof of his observatory except on one occasion, when he accepted an invitation from Humboldt to attend a meeting of natural philosophers at Berlin. His first work on the "Theory of Magnetism" was published in 1832 (Intensitas vis Magneticæ Terrestris ad Mensuram Absolutam Revocata). Shortly afterward he constructed in conjunction with Professor Wilhelm Weber new apparatus for observing the earth's magnetism. One of these instruments is the bifilar magnetometer. With Weber's assistance he erected in 1833, at Goettingen, a magnetic observatory, free from iron. From this observatory he sent telegraphic signals to a neighboring town, thus demonstrating for the first time the practicability of an electromagnetic telegraph. He organized the Magnetic association, whose continuous observations (1836-41) on fixed days extended from

CARL FRIEDRICH GAUSS.

Holland to Sicily. The results of the observations were published from 1836 to 1839. Gauss was well versed in general literature and the chief languages of modern Europe, and was a member of nearly all the leading scientific societies in Europe. His collected works were published by the Royal Society of Goettingen, comprising seven volumes, 1863 to 1871: (1) "Disquisitiones Arithmeticæ;" (2) "Theory of Numbers;" (3) "Analysis;" (4) "Geometry and Method of Least Squares; (5) "Mathematical Physics;" (6) "Astronomy," and (7) "Theoria Motus Corporum Cœlestium." Sir William Thomson proposed the name of Gauss for the unit of intensity of magnetic field. This practical unit has been generally adopted. It is equal to 10^8 C. G. S. units.

CHAPTER IV.

ANDRE MARIE AMPERE.

Andre Marie Ampere was born at Lyons, January 22,1775, and died at Marseilles June 10, 1836. Ampere is the founder of the science of electro-dynamics. He was enthusiastic in the pursuit of knowledge from his childhood, and according to tradition he worked out sums by means of pebbles before he knew the figures. In later life he was accustomed to say that he knew as much about mathematics when he was 18 as ever he knew, but his reading embraced history, travels, poetry, philosophy and the natural sciences. From about 1796 Ampere gave private lessons at Lyons in mathematics, chemistry and languages. In 1801 he removed to Bourg, where he was professor of physics and chemistry. After two years' absence he returned to Lyons as professor of mathematics at the Lyceum. In 1809 he was elected professor of analysis at the Polytechnic School at Paris. Here he continued to prosecute his scientific researches and his multifarious studies. He was admitted to membership in the institute in 1814. He established the relations between electricity and magnetism. On his development of the science of electro magnetism, or as he called it, "electro-dynamics," his fame rests. On the 11th of September, 1820, he heard of the

ANDRE MARIE AMPERE.

discovery of Professor Oersted, of Copenhagen, that the magnetic needle might be deflected by a voltaic current. He set to work at once to develop the important consequences which this discovery involved. Physicists had long been looking for the connection between magnetism and electricity, and had, perhaps, inclined to the view that electricity was in some way to be explained as a magnetic phenomenon. Such ideas in part led Oersted to his discovery. Ampere proved that the explanation was to be found in an opposite direction. He discovered the ponderomotive action of one electric current on another, and by a series of well chosen experiments he established the elementary laws of electro-dynamic action. Starting from this point, by a brilliant train of mathematical analysis, he not only evolved the complete explanation of all the electro-magnetic phenomena observed before him, but predicted the discovery of many new facts. On September 18, 1820, he presented a paper to the Academy, containing a far more complete exposition of the phenomenon observed by Oersted, which he had in the interval investigated by experiments, and he proved that magnetic effects can be produced without magnets, but by means of electricity alone. In particular he showed that the attraction or repulsion of two wires connecting the opposite poles of a battery depends on whether the currents pass in the same or in opposite directions. According to his beautiful theory of magnetism, every molecule of magnetic matter is acted on by a closed electric current, and magnetization takes place in proportion as the direction of these currents approaches parallelism.

This theory of molecular currents gave an explanation of that connection between electricity and magnetism which had been the dream of previous investigators. Hardly any advance in the science of electricity can compare in point of completeness and brilliancy with the work of Ampere, if we except the discovery of the laws of induction by Faraday ten years later.

Ampere anticipated the invention of the electric telegraph, as he suggested in 1821 an apparatus having a separate wire for each letter.

To Ampere is due the invention of the solenoid and several other kinds of apparatus which he constructed for the purpose of demonstrating his theories experimentally. The great amiability and childlike simplicity of Ampere's character are well brought out in his "Journal et Correspondence," published by Madame Chevreux, Paris, 1872. His most remarkable reports are found in the publications of "L'Academie des Sciences," or in the "Annals de Physique et de Chimie." The Paris Electrical Congress of 1881 adopted the ampere as the practical unit of the strength of the electric current. This practical unit is equal to 10^{-1} of the C. G. S. unit.

CHAPTER V.

CHARLES AUGUSTIN COULOMB.

Charles Augustin Coulomb was born at Angouleme, June 14, 1736, and died at Paris, Aug. 23, 1806. Coulomb belonged to a noble family of Montpellier. He chose the profession of military engineer. He gained great distinction in 1773, by his "Statistical Problems Applied to Architecture," which he presented to the Academy of Sciences in 1778. He shared with Van Swinden the prize for improvements in the construction of compasses. In 1781 he was stationed permanently at Paris. He was appointed inspector of public instruction in 1802, but his health was already very feeble, and four years later he died. He had the rank of lieutenant-colonel of engineers. His fame rests chiefly on his most elaborate and important investigations in electricity and magnetism, and on his invention of the torsion balance in 1777. This instrument has since his time been universally used in all delicate researches, particularly in the measurement of electrical and magnetic actions. Coulomb proved, by a series of elaborate experiments, in opposition to the generally accepted theories of Cavendish, that electricity, like gravity, varied in the inverse ratio of the square of the distance. Adopting the two-fluid hypothesis, Coulomb investigated the distribution of electricity on the surface of bodies. His experiments on the dissipation of electricity possess a high value. He found that a thread of gum-lac was the most perfect of all insulators; it insulated ten times as well as dry silk thread. He found that a silk thread covered with fine sealing wax insulated as effectually as gum-lac when it had four times its length. He ascertained that the dissipation of electricity along insulators was chiefly due to adhering moisture, but in some measure also to a slight conducting power. His writings were collected by the Societe de Physique, and thanks to Monsieur Potier, form Volume I of the "Memoirs Relating to Physics." The Paris Electrical Congress of 1881 adopted the name of Coulomb as the practical unit of electrical quantity. The coulomb is equal to 10^{-1} of the C. G. S. unit of quantity.

CHAPTER VI.

COUNT ALESSANDRO VOLTA.

Count Alessandro Volta was born at Como, Feb. 18, 1745, and died in the same city, Mar. 6, 1827. He was appointed professor of physics in the Gymnasium of Como in 1774. In 1777 he left his native city and traveled through Switzerland, where he and De Saussure became intimate friends. In 1779 a chair of physics was founded in Pavia and Volta was chosen to occupy it. In 1782 he undertook a journey through France, Germany, Holland and England, and became acquainted with nearly all the scientific celebrities of that day. In 1791 he received the Copley medal of the Royal Society. In 1801 Napoleon, then first consul of the French Republic, called him to Paris that he might see his experiments on contact electricity. A medal was struck in his honor. He was made a senator of the kingdom of Lombardy, member of the Academy of Sciences, and received 6,000 francs as a present. In 1815 the emperor of Austria made him director of the philosophical faculty of Padua. In 1819 he retired and settled in his native town. Volta is the inventor of the electrophorus, the condenser, the straw electrometer and the electric pile. Volta's electric pile was first described in a letter to Sir J. Banks, then president of the Royal Society. This letter, which was dated March

COUNT ALESSANDRO VOLTA.

20, 1800, was read before the society on June 26 of that year. The pile consisted of a number of disks of zinc and an equal number of silver or copper disks. The zinc and copper plates were in contact, and each pair was separated by porous matter which was kept moist. He described a number of experimental results obtained with this pile, and finally showed that all the effects produced were the same as those which could be obtained from electrical machines and that therefore "galvanism" and "electricity" were identical. Volta was led to the invention of the electric pile by the astonishing discoveries of Galvani in 1790. It is very instructive to read the letters and essays in which Volta describes his observations and his reasoning which gradually led him up to the construction of the electric pile. The muscle of the frog soon appeared to him to be nothing but a very delicate electrometer and not, as was first thought, the source of electricity. Volta lived to see the remarkable development of his science by Sir Humphrey Davy, Oersted and Ampere, but he was no mathematician, and the subject grew beyond his ability to grasp it. He recognized this fact with that frank honesty which is apparent in all his writings and during the last twenty-five years of his life he published nothing on electrical subjects. The Paris Electrical Congress of 1881 adopted the word volt (abbreviation of the name Volta) as the practical unit of electromotive force. It is equal to 10^8 C. G. S. units.

CHAPTER VII.

GEORG SIMON OHM.

Georg Simon Ohm was born at Erlangen, Bavaria, March 16, 1789, and died at Munich, July 17, 1854. The exact year of his birth is in doubt. Ohm was the son of a locksmith in Erlangen, Bavaria, and in his boyhood, following the custom prevailing in European states, he worked in his father's shop. Very early in his life he turned his attention to physical science, and having been educated in the university at Erlangen, and becoming an accomplished mathematician, he was in 1808 appointed professor of physics in the gymnasium of Cologne. In 1817 he became professor of mathematics in the Jesuits' college in Cologne, and in 1818 published his first work, on the "Elements of Geometry."

After a few years in Cologne he resigned his professorship and went to Berlin. He had become deeply interested in the phenommena of galvanic electricity. Galvani had discovered in 1790 that the contact of metals produced a current of electricity which developed muscular contraction in the frog, and in 1800 Volta had invented the electric pile. Pushing his researches in these directions, by the aid of his mathematical attainments, Ohm became convinced that the flow of the electric current was governed by fixed laws, and

GEORG SIMON OHM.

he bent his energies to the discovery of those laws. The result of his studies was embodied in his famous work published in 1827 and entitled "Die Galvanische Kette Mathematisch Bearbeitet" (the galvanic circuit mathematically determined). This work was only a pamphlet, but its importance was far-reaching, for here is found what has ever since been known as "Ohm's law." In 1833 Ohm became the director of the Polytechnic School at Nuremberg. In 1852 he was made professor of experimental physics in the University of Munich.

Ohm's law completely changed the methods of measuring electric quantities. Before his discovery the quantitative circumstances of the electric current had been very vaguely indicated by the words "intensity" and "quantity," but these words indicated nothing definite. By Ohm's law, however, it became for the first time possible, accurately to define and measure electromotive force, strength of current and resistance.

Ohm's law states that the current strength is directly proportional to the electromotive force, and inversely proportional to the resistance. This is generally written as a formula $C = \frac{E}{R}$; in which C represents current strength (in amperes), E electromotive force (in volts), and R resistance (in ohms.)

It may be doubted whether Ohm's investigations could have been made without the aid of the magnificent work of Fourier on the conduction of heat. In fact, the equation for the propagation of electricity formed on Ohm's principles, is identical with that of Fourier for the propagation of heat; and if in Fourier's solution of any problem of heat conduction, we change the word "temperature" to "potential" and write "electric current" instead of "flux of heat," we have the solution of a corresponding problem of electric conduction.

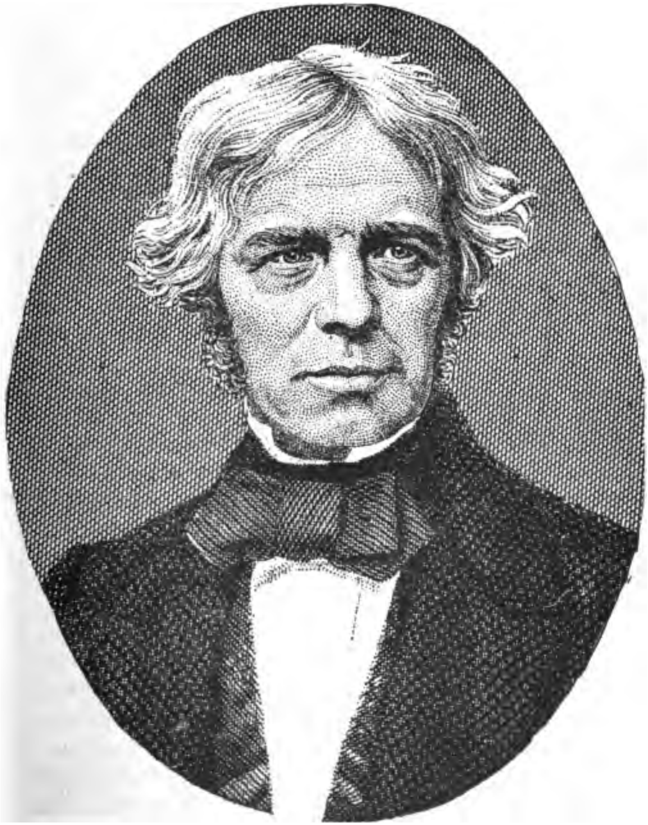
Ohm introduced for the first time into the theory of the galvanic pile the equivalent of the modern word "potential." Ohm's word was "electroscopic force" or "tension," and he showed that with the same current strength the fall of potential is uniform along a homogeneous linear conductor of even cross-section.

Ohm continued a long course of experiments with the thermo-electric pile, and when he had become thoroughly satisfied as to the correctness of his theory, he published his book. Like almost all other discoverers he was ahead of his time. The value of Ohm's work was but imperfectly recognized until it was stamped by the award of the Copley medal of the British Royal Society in 1841. This society is now co-operating with German scientific societies in the erection of a statue in honor of Ohm at Munich, the capital of Bavaria, his native country. Since his birth a century had passed on March 16, 1889. The Electrical Congress of Paris in 1881, adopted Ohm's name as that of the practical unit of resistance. The ohm is equal to 10^9 C. G. S. units.

CHAPTER VIII.

MICHAEL FARADAY.

Michael Faraday was born at Newington near London, Sept. 22, 1791, and died at Hampton Court, Sussex, on August 25, 1867. His father, James Faraday, a native of Yorkshire, obtained his livelihood as a working blacksmith. Faraday's education as a child, was of the most ordinary description, comprising little more than the rudiments of reading, writing and arithmetic, obtained at a common day-school in the neighborhood. At 13 he went to Mr. Riebau, of Blandford street, to whom he was apprenticed in the following year, to learn the business of bookseller and bookbinder, and continued to work at that trade till 1812. During his term of apprenticeship, a few scientific works occasionally fell into his hands. These he read with avidity, and aided by patient study and such rough experiments in chemistry as could be accomplished by a youth with little leisure, and still less pocket money, he gradually mastered their contents. Among these were "The Treatise on Electricity," the "Encyclopædia Britannica," and Mrs. Marcet's well-known "Conversations on Chemistry." The perusal of the former led to the construction of his first electrical machine with a glass phial, on which he afterward improved by



MICHAEL FARADAY.

constructing another with a proper cylinder, and added other simple apparatus for the purpose of making a variety of experiments with electricity. Through the kindness of Mr. Dance, a member of the Royal Institution and a customer of his master, Faraday was enabled to attend the last four lectures delivered in that building by Sir Humphrey Davy in the early part of 1812. Of these he took careful notes, from which he wrote out the lectures in a fuller form, interspersing them with such drawings as he could make to illustrate their contents. His strong desire for some scientific occupation, even of the humblest kind, induced him to write in the December following to Sir Humphrey Davy, inclosing his notes and illustrations as a proof of his earnestness in the cause of science. The reply was prompt as well as kind and favorable, nor was it without its results. Early in 1813, his patron, acting for the managers of the Royal Institution, offered him the situation of chemical assistant under himself, as honorary professor, and Mr. Brande as professor of chemistry. This post he accepted, and shortly afterward entered upon his duties, taking up his residence at the Royal Institution, where he chiefly resided. In the autumn of the same year Mr. Faraday went abroad as assistant and amanuensis of Sir Humphrey Davy, and returned to England in 1815, when he resumed his place at the Royal Institution. After a number of varied experiments, of which he published accounts from time to time in scientific journals, in 1820 he discovered chlorides of carbon, in 1821 the mutual rotation of the magnetic pole and an electric current, and in 1823 some new and important facts as to the condensation of gases. In 1829 he labored hard, and as he thought at the time fruitlessly, on the production of optical glass; but though unsuccessful in his immediate object, his experiments produced the heavy glass which afterward proved of great assistance to him in his magnetic investigations. In 1831 the series of "Experimental Researches in Electricity," published in the "Philosophical Transactions," began with the development of the induction of electric currents, and the evolution of electricity from magnetism. He took up the investigation of the chemical decompositions effected by the electric current. In 1833 he announced his great law of electro-chemical equivalents, which made an epoch in the history of this department of electricity. He recognized, and for the first time thoroughly explained, the essential features of the phenomenon. Faraday's discovery gave a new measure of the current, and he invented the voltameter. In 1846 he received at one time the Royal and the Rumford medals for his discoveries in diamagnetism, and of the influence of magnetism upon light. In 1847 he declared the magnetic character of oxygen, and the magnetic relations of flame and gases.

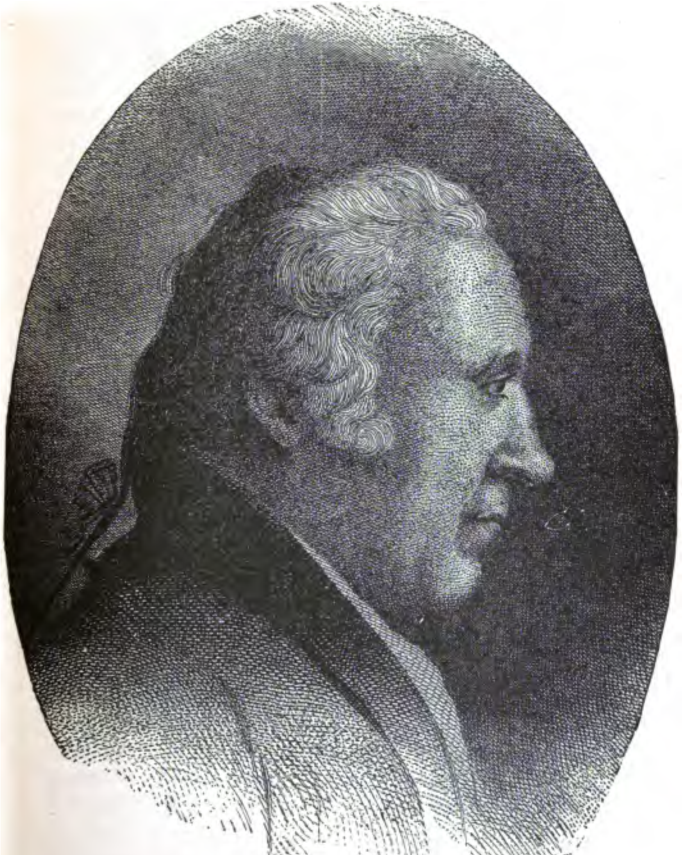
It should be observed that the "Researches," though termed "experimental," contain many hypothetical ideas and many inquiries into theories generally adopted up to their time. Among these may be specified the consideration respecting static induction, atmospheric electricity and those relating to lines of force, both representative and physical, which, having sufficiently stated his views, he was content to leave for solution to time and future experience. It may be added that his last hypothetical view relates to the conservation of force, a generalization which later researches have established; and that one of his latest papers treats of the division of gold and other metals. The researches of Faraday were pursued almost exclusively in the Royal Institution, Albemarle street, London, where he delivered lectures on scientific subjects every year from 1827, when he first appeared at the lecture table in the great theater. In conjunction with his friend, Mr. Brande, he had, for some three years previously, delivered early morning lectures to students in the laboratory. In 1833, when Mr. Fuller founded the chair of chemistry called after his name, in the Royal Institution, he nominated Mr. Faraday the first professor, expressly desiring that he should hold the chair as long as he was attached to the institution without being required to give lectures or having any other duties exacted of him in consideration of the value of his researches to the cause of science. In November, 1835, Professor Faraday received from Lord Melbourne's government a pension of £300 per annum as a recognition of the importance of his scientific discoveries.

In 1836 he was appointed scientific adviser on lights to the Trinity House, and became a member of the senate of the University of London. In 1825 Professor Faraday was elected corresponding member of the Academy of Sciences, at Paris; in 1825, a fellow of the Royal Society; and in 1832, the University of Oxford conferred upon him the honorary degree of Doctor of Civil Law. Numerous foreign orders were showered upon him, and he was a member of many learned and scientific bodies. He might have had a title, but his ambition did not lie that way, and he always refused such offers. The Paris Electrical Congress of 1881 named in his honor the practical unit of electric capacity, the "Farad." This term was also applied previously to the unit of current strength which is now measured in amperes. One farad is equal to 10^{-9} of the C. G. S. unit.

CHAPTER IX.

JAMES WATT.

James Watt was born at Greenock, January 19, 1736, and died at Heathfield, Aug. 19, 1819. His father was a small merchant at Greenock, who lost his little fortune by unsuccessful speculation, and the son at an early age was thrown on his own resources. He developed, when a boy, a taste for mechanics, and at the age of 19 went to London to learn the trade of scientific instrument maker. In 1756 he visited Glasgow to obtain work in repairing astronomical instruments, and subsequently tried to establish himself as an instrument maker in Glasgow. As he had not served the full term of apprenticeship the City Guilds refused him permission. The college took him under its protection and in 1757 he possessed the title of mechanical instrument maker to the university. Here Watt became acquainted with Black, the discoverer of latent heat, then a lecturer on chemistry, and a student by the name of Robinson, who afterward became professor of natural philosophy. The three frequently discussed the possibility of improving the steam engine, of which, at that time, Newcomen's was the most advanced type. His engines were at that time applied only to pumping water, generally in mines. They



JAMES WATT.

were so clumsy and wasteful of fuel that they were but little used. Watt commenced a very close study of this steam engine, and of the properties of steam. In 1769 he took out his first patent, which covers nearly all the features of the modern steam engine. Watt's second steam engine patent is dated 1781. It describes five different methods of converting the reciprocating motion of the piston into motion of rotation so as to adapt the engine for driving ordinary machinery. The simplest way of accomplishing this was by a crank and fly wheel, a method which is still used to-day. In 1782 he took out the third patent covering a double acting engine; that is to say, both ends of the cylinder were alternately put in communication with the boiler and the condenser; up to that time only one end of the cylinder was thus connected. Watt also covered in this patent, the system of expansive working in which the admission valve is closed after a portion only of the stroke is performed and the steam inclosed in the cylinder is then allowed to expand during the remainder of the stroke, thus doing additional work upon the piston. In 1784 he took out his fourth patent describing the well-known "parallel motion," an arrangement of links, by which the top of the piston rod is connected to the bottom, so that it may either pull or push, and is at the same time be guided to move in a sensibly straight line. Watt is considered the father of modern steam engineering. He invented the throttle valve and centrifugal governor by which the speed of rotative engines was automatically controlled. He is also the inventor of the steam engine indicator, which draws a diagram of the relation of the steam pressure to its volume as the stroke proceeds. This instrument has played the most important part in the evolution of the steam engine. No engineer of to-day underestimates its value, and it is a surprising fact that the inventor of the modern steam engine also invented the instrument by which the working of the engine could be determined. Watt was the inventor of the letter copying-press; he patented the device in 1780. In the year 1800 he retired from business and spent the remainder of his life at Heathfield Hall, his home near Birmingham, where he devoted his time to mechanical pursuits. The late Sir William Siemens proposed in 1882 to name the unit of activity or power exerted by one volt-ampere the watt, in memory of the name of the famous inventor. This practical unit has been generally adopted. It is equal to 10^7 C. G. S. units.

CHAPTER X.

JAMES PRESCOTT JOULE.

James Prescott Joule was born at Salford, near Manchester, December 24, 1818, and died at Sale, near Manchester, October 11, 1889. When he was fifteen years of age he became a pupil in chemistry of Dalton, who first established the atomic theory and the principle of the indestructibility of matter. He entered into his work with enthusiasm, and not many months elapsed before he commenced a series of experiments with rude apparatus of his own contrivance. One of his first papers related to an electro-magnetic engine. It was published when he was nineteen years of age. Some idea of the immense amount of wŏrk performed by him may be gained when it is stated that in the Royal Society list there are titles of ninety-seven papers prepared by him, besides twenty other important papers relating to researches undertaken by him in connection with Sir William Thomson, Sir Lyon Playfair and others. In these papers a great variety of scientific subjects was treated. In many of his experiments he had met with great difficulties arising as he said "from incomplete descriptions of apparatus, and from the arbitrary and vague numbers which are used to characterize electric currents. I have therefore determined for my own part to abandon my old quantity numbers, and to ex-

JAMES PRESCOTT JOULE.

press my results on the basis of a unit which shall be at once scientific and convenient." The unit quantity of electricity, according to his method, was the quantity necessary to decompose nine grains of water. As a unit of resistance he adopted a copper wire of specific dimensions. He devised many improvements in galvanometers and as a result of a series of experiments laid the foundation for the department of thermo-dynamics. The statement of his discovery of the mechanical equivalent of heat was made at the Cork meeting of the British Association in 1841. During the next few years he presented to learned societies many communications on the subject. These preliminary papers were summed up in an elaborate paper which he read before the Royal Society in 1849. He summarized his investigations as follows: "The quantity of heat produced by the friction of bodies, whether solid or liquid, is always proportional to the quantity of force expended, and the quantity of heat capable of increasing the temperature of a pound of water by one degree Fahrenheit, requires for its evolution the expenditure of a mechanical force expended by the fall of 772 lbs. through the space of one foot."

Seguin in France and Mayer in St. Petersburg had also made noteworthy advances toward the establishment of the mechanical equivalent of heat. A hot controversy arose, especially in England, as to the relative merits of Mayer and Joule.

Joule distinguished himself also by his experiments with electric motors or, as they were formerly called, electro-magnetic motors. Early in 1841 he gave a lecture in the Royal Victoria Gallery in Manchester, in which he gave the results of his experiments, referring also to what had been done by Jacobi in St. Petersburg in the way of applying electro-magnetism as a motive power (see Jacobi). Joule also found, experimentally, that the quantity of heat developed by an electric current in a conductor is directly proportional to the resistance of the conductor and to the square of current strength and to the time that the current lasts.

This law, known as "Joule's law," is now generally expressed by the formula:

$$Wj = \frac{C^2 \times R \times t}{4.2}$$

Where Wj represents the quantity of heat or work; C the current strength in amperes; R the resistance in ohms; t the time in seconds and 4.2 Joule's equivalent.

Dr. Joule has figured but little in the fields of popular science. He became a fellow of the Royal Society in 1850, received the degree of B. C. L. from Oxford, of LL. D. from the universities of Dublin and Edinburgh, and was president of the British association in 1873.

His work in pure science which was followed by practical results, has been appreciated and gold medals and other marks of honor have been showered upon him. It 1878 a pension of £200 a year was conferred upon him by the British government. He lived a retired life as the result both of great modesty and poor health.

Siemens proposed in 1882 the "Joule" as a practical unit of electric work (heat or energy). This practical unit has been generally adopted. It is equal to 10^7 C. G. S. units.

CHAPTER XI.

DR. WERNER VON SIEMENS.

Dr. Werner von Siemens was born at Lenthe in Hanover, Dec. 13, 1816. He is the eldest and most famous of four brothers, namely: Carl Wilhelm (Sir William Siemens) born at Lenthe, April 4, 1823, died in London Nov. 19, 1883; Friedrich, born at Menzendorf in 1825, and Carl, born at Menzendorf in 1829. Werner was educated at the Lubeck Gymnasium. He joined the Prussian artillery in 1834, where his eminent talents soon attracted notice, and, having passed through the military schools, he obtained the rank of lieutenant in 1837. While still holding this appointment in the army he applied himself with great zeal to the study of practical chemistry and physical sciences, and became the inventor of the process of electro-gilding, the differential governor and the electro-automatic recording telegraph, for all of which patents were granted him in Prussia. As member of a commission of the Prussian General Staff for the introduction of the electric telegraph system in place of the optical telegraphs, he proposed, in 1847, the application of subterranean conductors, insulated by gutta-percha. Successful experimental lines were operated, the wires of which were coated with gutta-percha by means of a press invented by him for that purpose. The press is still used in

DR. WERNER VON SIEMENS.

the manufacture of cables. With the help of these insulated wires he first succeeded, with the assistance of Prof. Himley, in firing submarine mines by electric ignition, in the spring of 1848. These mines were designed for the protection of the harbor of Kiel from the Danish fleet. In the same year he directed the construction of the first great telegraph line in Germany, between Berlin and Frankfort-on-the-Main, and in the following year planned the subterranean line between Berlin and Cologne.

Dr. Siemens left the government service in 1850, and subsequently devoted himself exclusively to scientific studies and private enterprises, In 1847 he had already laid the foundation of the telegraph manufactory conducted by him under the firm name of Siemens & Halske in Berlin, the celebrated establishment which was destined to become, and at present is, one of the chief centers for the application of electricity to the industrial arts. Its world-wide reputation, acquired within a short time, led him to open branch works in London and St. Petersburg, which soon developed into large independent concerns under the management of his younger brothers, Wilhelm and Carl.

Dr. Siemens' personal achievements are to be found in the fields of science as well as in the technical arts. His scientific merits induced the University of Berlin to confer on him the degree of Doctor of Philosophy, *honoris causa*, in 1860. He was honored by admission to membership in the Academy of

Sciences in Berlin in 1874, and subsequently in many other academies and societies. Among his many and varied achievements in matters relating to science and technical arts may be mentioned as particularly noteworthy, the invention and practical application of a standard unit of resistance known as the Siemens unit, the development of methods for testing underground and submarine cables, and of determining the position of faults, the invention of polarized relays, of the so-called Siemens armature, and of the dynamo-electric machine, the principle of which he published first at the meeting of the Berlin Academy of Sciences on January 17, 1867, the electric railway, and of numerous other appliances, including the pneumatic dispatch tube system, and the Siemens alcoholometer for registering the quantity of absolute alcohol contained in any alcoholic liquid passing through the instrument.

Dr. Siemens has been appointed a member of the Prussian Order "Pour le Merite," and has become the recipient of many other distinctions and honors. The German emperor created him a noble. He is honorary member of the English Institution of Electrical Engineers, and is corresponding secretary for Germany.

His many papers read before scientific societies up to 1881 were published in book form, "Gesammete Abhandlungen und Vortraege," published in Berlin by Julius Springer in 1881.

CHAPTER XII.

SIR WILLIAM SIEMENS.

Sir William Siemens (christened Carl Wilhelm) was born at Lenthe in Hanover, April 4, 1823, and died in London Nov. 19, 1883. He was educated in the Polytechnic School of Magdeburg and the University of Goettingen. He visited England at the age of 19, to introduce a process of electro-plating, which he had jointly invented with his brother Werner. He subsequently returned to Germany and entered as a pupil the engineering works of Count Stolberg at Magdeburg. In 1844 he went again to England to introduce a new invention of his brother Werner, the differential governor for steam engines: He then made England his home, and in 1859 became a naturalized British subject. In 1851 he established himself as an engineer; he worked mainly in two departments, in the application of heat and the application of electricity. He gained great reputation in both fields. The scientific papers which he published from time to time would have alone sufficed to establish his reputation. He was elected in 1862 to membership in the Royal Society and later he became president of the Institute of Mechanical Engineers, the Society of Telegraphic Engineers, the Iron Steel Institute and the British association.

SIR WILLIAM SIEMENS.

He was given honorary degrees by the universities of Oxford, Glasgow, Dublin and Wuertzburg. He was knighted by the queen in 1881. Siemens originated a great number of valuable inventions. Among others he introduced in 1856 the regenerative furnace, the idea of his brother Friedrich, with whom William had associated himself. Siemens was a strong believer in gaseous fuel, and he anticipated that its use would in time supersede that of coal for domestic and industrial purposes, cheap gas being supplied, either from works or directly from the pit. One of his last inventions was a house grate, in which to burn gas and coke. This combustion he regarded as a possible cure for city smoke. Another of his inventions is the Siemens electric furnace, in which the intensely hot atmosphere of the electric arc between carbon points melts refractory metals. He also invented a water-meter, an electro-thermometer, a pyrometer, an attraction-meter, and a bathometer, by which the depths of the sea can be found without a sounding line.

A number of his most valuable papers were published under the title, "Einige Wissenchaftlich-Technische Fragen der Gegenwart," issued in Berlin by Julius Springer, 1879.

CHAPTER XIII.

JOHN FREDERICK DANIELL.

John Frederick Daniell was born in London March 12, 1790, and died in London March 13, 1845. Daniell received from his father, a barrister, an excellent classical education. He displayed from his early years a great liking for natural science. He studied chemistry, and started, in 1816, with Professor Brande, the *Quarterly Journal of Science and Art*. In 1823 he published his meteorological essays. In 1831 he was appointed first professor of chemistry at King's College. During the succeeding years he was engaged in investigations of heat and electricity. In 1832 he received the Rumford medal of the Royal Society. In 1837 he was awarded the Copley medal for his invention of the sulphate of copper battery, which bears his name. In 1842 he received the Royal Medal. He is the only person who ever received all three medals in the gift of the Royal Society. The Daniell cell is still used as a standard of electromotive force, and was at the time of the invention a great improvement over other primary batteries. The name Daniell was formerly used for the practical unit of electromotive force, being equal to the elec-

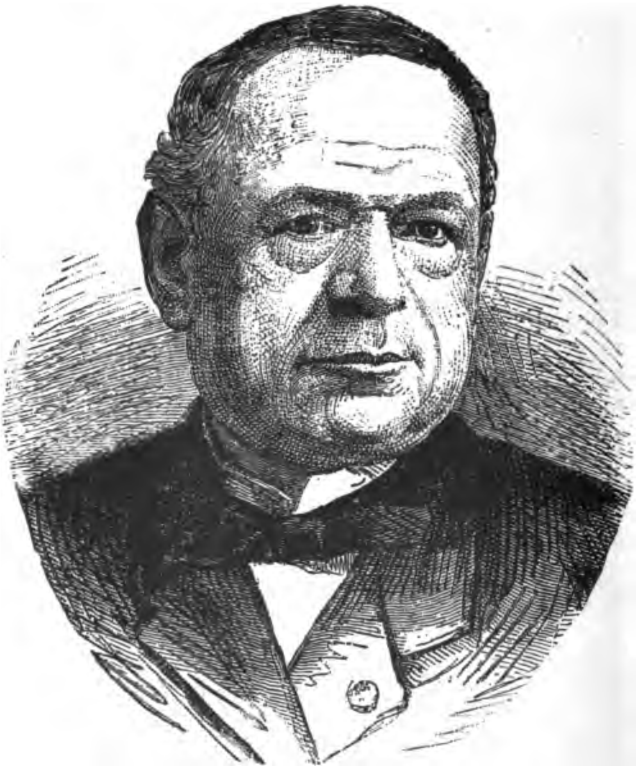
JOHN FREDERICK DANIELL.

tromotive force of one Daniell cell. This name has become obsolete now, and is replaced by the volt, which is equal to .926 standard Daniell cell.

CHAPTER XIV.

MORITZ HERMANN VON JACOBI.

Moritz Hermann von Jacobi was born at Potsdam, Sept. 21, 1801, and died at St. Petersburg, March 10, 1874. Jacobi received a good common school education. At the age of 28 he went to Russia, and soon attracted attention by his researches in physics. He invented electrotyping simultaneously with Thomas Spencer, in Liverpool, in 1837. In 1839 Jacobi first succeeded in propelling a boat on the River Neva at St. Petersburg by means of a galvanic battery, and an electro-magnetic motor. His motor was constructed after the Ritchie principle, and consisted of four stationary and four movable electro-magnets arranged around a horizontal shaft, with a paddle wheel on each end. The battery consisted of 64 zinc-platinum cells. This scientific triumph was, however, not crowned by commercial success, for the simple reason that primary battery power then was and still is too expensive. Jacobi laid down the fundamental theories of electric motors. He proposed practical units of resistance and current strength. (See Weber.) He constructed electric telegraphs in St. Petersburg; the most extensive line being 18 miles in length, between two of the imperial residences. He conducted many experiments on these



MORITZ HERMANN VON JACOBI.

lines, and made the important discovery that by using the earth as a "return," the circuit was completed. In 1840 he published "Die Galvanoplastik" (The Art of Electrotyping), a work which gained him admittance to the Imperial Academy at St. Petersburg. His principal works were published in the "Poggendorff's Annalen" from 1834 to 1857. The most important are: "Applications of Electro-Magnetism," "The Phenomena of Induction in the Voltaic Pile," "The Laws of Electro-Magnets," "Reports on the Application of Galvanism to Electrotyping," "The Ignition of Gunpowder," etc.

MODIFICATIONS

— OF THE —

PRACTICAL ELECTRICAL UNITS.

BY PROF. H. S. CARHART.

The readers of the WESTERN ELECTRICIAN are indebted to F. B. Badt for his article on "Practical Electrical Units," and particularly for his entertaining biographical sketches of some of the great physicists. The importance of the subject in exact electrical measurements leads me to add a small contribution in order to explain what must often be a source of perplexity to workers in the electrical field.

Before proceeding to the main topic may I venture to make a correction or two on points in Mr. Badt's table which do not appear to conform exactly to the most general practice? I remark first, that the symbol of strength of pole is m and not M as printed.* The capital letter is quite universally used, at least in English, to denote magnetic moment, or the product of strength of pole by length of magnet. Again, C is unfortunately used both for strength of current and for capacity. The letter K, which Mr. Badt has used for capacity, is quite generally used to denote "specific inductive capacity." It would be an improvement to adopt the usage of some writers who employ F for capacity.

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*The table has been modified in accordance with this suggestion.

I should not venture to define a volt as "0.926 standard Daniell cell." It would be necessary to define what standard Daniell is referred to. If zinc sulphate of density 1.4 and copper sulphate of density 1.1 are used, then the electromotive force is 1.072 legal volts, and the volt is about .933 of this standard. If equidense zinc and copper sulphates are used the electromotive force is 1.102, or possibly 1.104 legal volts, and the volt is only .907 of the standard Daniell. The more usual practice is to use solutions of the first pair of densities, in which case the voltage is 1.072.*

The unit of self-induction, which is simply a length, the recent Paris Congress agreed to call a "Quadrant"* and not a "Secohm," as Professors Ayrton and Perry had proposed.

But I did not set out to make corrections, but to speak of some important modifications to which several of the electrical units are subject. Since we have in use at least three units of resistance (not to mention the Siemens unit) the B. A., the legal and the Rayleigh ohm, we have also as many modifications of all units which are defined or measured by means of the unit of resistance. Independent absolute measurements have been made of the ohm and of the ampere. The volt is then made to depend upon the current and the resistance. Hence, the current being given, the number of units of the electromotive force varies directly as the number of units of resistance; and therefore, the values of these units themselves vary in the same ratio. Hence, as the legal ohm is equal to 1.0114 B. A. units, according to Lord Rayleigh's researches, the legal volt is equal to 1.0114 B. A. volts. The legal ohm being the resistance of a column of mercury one square millimeter in cross-section and 106 cm. in length under standard conditions, and the true ohm, according to Lord Rayleigh, being represented by a resistance of a similar column of mercury 106.21 cm. in length, it follows that the Rayleigh ohm is 2 per cent. greater than the legal ohm, and the Rayleigh volt 2 per cent. greater than the legal volt. Lord Rayleigh's form of the Clark standard cell has an e. m. f. of 1.435 Rayleigh volts at 15° C. Hence, it is equal to 1.438 legal volts at the same temperature, since the number of volts in any source of e. m. f. is inversely as the value of the unit employed. This is expressed by saying that the numeric is inversely as the value of the unit. Hence, if a potential difference is expressed in B. A. volts it is necessary to divide by 1.0114 in order to reduce to legal volts since one legal volt equals 1.0114 B. A. volts.

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*The table has been modified in accordance with this suggestion.

Similar perplexities follow with the numerical value of a current if while B. A. ohms are employed the e. m. f. is expressed in legal volts. Such cases may easily arise in practice.

More perplexing still, perhaps, is the question of the numeric of a capacity. If in the absolute measurement of capacity B. A. units of resistance are employed, it is quite as necessary to take into account the corrections to be applied to the resistances as the correction of the clock in getting the vibration frequency of the tuning fork or circuit breaker used to charge and discharge the condenser. It will be seen from the table of "dimensions" that capacity is inversely as a velocity $(L{-}L^{-1}T^{2})$, that is, inversely as a resistance, since a resistance in electro-magnetic units is a velocity. Hence, the microfarad is inversely as the ohm employed, and the numeric expressing the capacity in microfarads is directly as the unit of resistance. For instance, a one-third microfarad condenser, measured in terms of B. A. units, equals ⅓x1.0114, or .3371 microfarad in legal units. Conversely a ⅓ legal microfarad equals about 0.33 B. A. microfarad. The older condensers were all adjusted in conformity with the B. A. ohm, and hence they are larger than their nominal value when their capacity comes to be expressed in legal units

Suppose again, that we are using Maxwell's method of comparing a co-efficient of self-induction with the capacity of a condenser. In this case $L = Q\ R\ C$, in which Q and R are resistances and C is the capacity of the condenser. The resistances varying directly as a length and the capacity varying inversely as a length, it will be seen that the co-efficient of self-induction L, varies directly as a length, or has the dimensions of a line. Hence, the numerical value of the co-efficient of self-induction of a coil will vary inversely as the unit of resistance employed or directly as the numeric of the resistances. If B. A. units of resistance and capacity are employed, the self-induction will be 1.0114 times larger than if the resistances and capacity are expressed in legal units.

Whether electrical quantities are expressed in legal or B. A. units, may seem to many quite an indifferent matter; but the difference is over 1 per cent., and no such error as that should be permitted in making electrical measurements of any importance, taking into consideration the precision which modern methods permit.

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